30 Years of Denmark Strait Overflow observations linked with decadal wind stress and hydraulic forcing variability

Andreas Macrander[1]*, Héðinn Valdimarsson[2], Steingrímur Jónsson[2,3], Detlef Quadfasel[4]
1 Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven. * Andreas.Macrander@awi.de
2 Marine Research Institute, Reykjavík. **3** University of Akureyri. **4** Institut für Meereskunde, Hamburg.

1 Introduction

The Denmark Strait Overflow (DSO) is the densest source of North Atlantic Deep Water, that forms the deep return flow of the Atlantic Meridional Overturning Circulation.

Direct observations by ADCPs deployed at the 650 m deep sill exist for the period 1996-2006.

Here, the ADCP measurements are compared with upstream hydrographic profiles and NCEP wind stress data to obtain DSO transport estimates for the past decades.

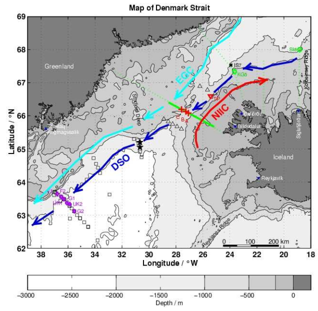


Fig. 1: Denmark Strait. EGC: East Greenland Current. NIIC: North Icelandic Irminger Current. DSO: Denmark Strait Overflow. Mooring sites ADCP A,B,C at the sill; TP temperature sensor mooring and Kögur section (dotted green line with KG5) further upstream. Angmagssalik array 600 km downstream.

2 Upstream Pathways

A large part of the DSO approaches the sill in a current confined to the Iceland shelf edge: A lagged temperature correlation between TP mooring site and ADCP B reveals advection speed of 10 cm/s, consistent with direct current measurements (*Jónsson and Valdimarsson*, 2004)

In contrast to the East Greenland Current, the „Iceland shelf edge current" persistently flows towards the sill; it represents the coldest waters of the later DSOW.

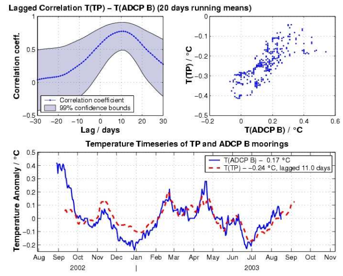


Fig. 2: Temperature correlation between TP mooring 93 km upstream of the sill, and ADCP B at the sill. Time lag of 11 days corresponds to advection velocity of 10 cm/s.

3 Kögur section

Icelandic hydrographic standard section 200 km upstream of DS sill
- bottle data since 1950
- 4 times per year since ~1975
- full CTD profiles since ~1990

Dense water height normally largest at KG5 → used as hydraulic reservoir height estimate here.

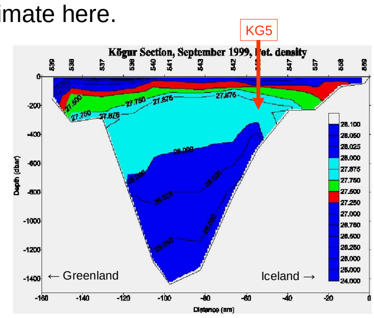
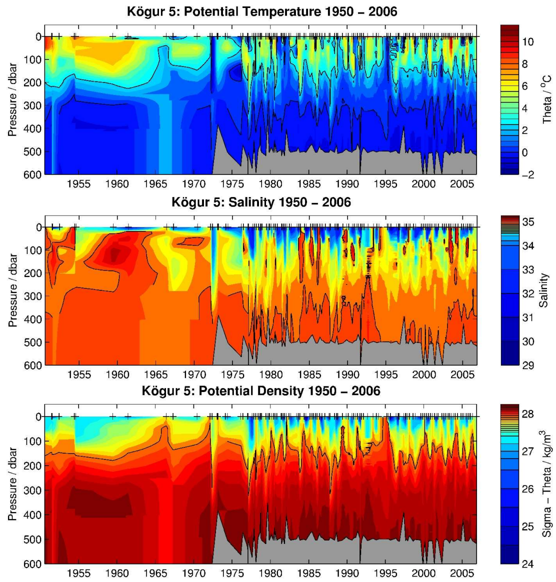


Fig. 3: Kögur section - σ_Θ Sep 1999. Typically, the rise of the 28.0 and 27.8 isopycnals is located at station KG5. For geographical location, see Fig. 1.

4 Timeseries at Kögur 5: Θ / S / σ_Θ from 1950 to 2006



Despite of aliased short-term variability, long-term trends are evident:

- warm surface water maxima mid-80s and 2001-2005
- cold bottom water mid-80s & end-90s
- overall freshening of subsurface waters
- overflow waters: S minima ~1984 and 1994-2000.
- 27.8 isopycnal (upper DSOW boundary): maximum height ~1965-1972 and mid-90s

→ DS overflow variability…

Fig. 4: Time series at Kögur 5 1950-2006. + signs denote actual sampling dates. Top: Θ. Black contours mark 0°C and 2°C isotherms. Middle: Salinity. Black contour marks 34.9 isohaline. Bottom: σ_Θ. Black contour marks 27.8 kg/m³.

5 Forcing of DSO: Hydraulics

The density-driven overflow plume is hydraulically controlled (downstream descent, *F*=1, geostrophic balance; *Macrander et al.*, 2005,7). Since PV≠*const*., maximum transport is calculated according to *Stern* (2000):

$$\Psi_{Stern} = 9/16 \;\; 1/2 \;\; g'/f \;\; h_{eff}^2$$

with h_{eff} = height of 27.8 isopycnal above sill

Average values 1999-2004:

DSO transport (ADCP measured):	3.4 Sv
Hydraulic transport (KG5 Ψ_{Stern}):	1.9 Sv
=> residual transport	1.5 Sv

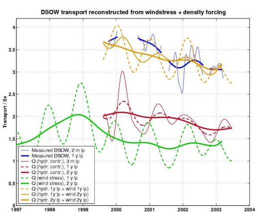


Fig. 5: DSO transport time series 1999 – 2004. ***brown: Kögur5-Ψ_{Stern}*** ***green: residual transport****, here empirically determined from Iceland Sea wind stress* *yellow: Reconstructed transport Ψ_{Stern} + wind stress.* *Compare with direct ADCP measurements (blue).*

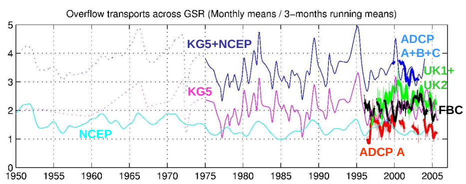


Fig. 7: Total time series DSO. Direct observations: Sill: ***ADCP A only****,* ***ADPC A+B+C****. Angmagssalik array:* ***UK1+UK2****. Compare with* ***Faroe Bank Channel overflow*** *(black). Reconstructions: Kögur 5 (Ψ_{Stern}). NCEP Wind stress. KG5+NCEP.*

7 Decadal estimates

- Hydraulically controlled transport 1975-2006 varies between 1 Sv and 3 Sv
- Positive correlation (but no direct causal link) with wind driven transport (1 – 2 Sv)
- Reconstructed DSO transport consistent with observations 1996 – 2006.
- Indication of positive correlation with NAO and/or Iceland Sea Wind Stress.
- Time series to be validated against numerical models

6 Forcing of DSO: Wind stress

The residual transport of 1.5 Sv corresponds to the observed 20 cm/s mean barotropic velocity due to the cross-strait surface height gradient and is likely wind-driven.

NCEP wind stress is largest over Denmark Strait and Iceland Sea. 1999 – 2004, local wind stress decreased by 20%, as did the residual transport. Correlation analysis suggests a time lag of 10 – 80 days depending on the distance to the DS sill.

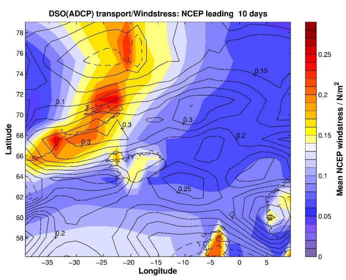


Fig. 6: Correlation of DSO transport 1999-2004 and NCEP wind stress (leading 10 days; black contours and labels). Colours in background: Average NCEP wind stress. Highest amplitude of correlated wind stress in DS and Iceland Sea.

Acknowledgements

This work is based on observations carried out by the former Sonderforschungsbereich 460 "Dynamik thermohaliner Zirkulationsschwankungen", funded by Deutsche Forschungsgemeinschaft at IFM-GEOMAR Kiel, and regular hydrographic surveys of the Marine Research Institute, Reykjavík, Iceland.
Field work in Denmark Strait: Research vessels "Bjarni Sæmundsson", "Meteor", "Poseidon", "Árni Friðriksson" and other Icelandic research vessels.

Further acknowledged contributions: Rolf Käse (modelling, IfM Hamburg), Uwe Send (SIO, formerly at IFM-GEOMAR).
Time series Angmagssalik UK1+UK2: Bob Dickson, Stephen Dye
Time series Faroe Bank Channel overflow: Bogi Hansen

References

Jónsson, S., and H. Valdimarsson, 2004: A new path for the Denmark Strait overflow water from the Iceland Sea to Denmark Strait, Geophys. Res. Lett., 31, L03305, doi:10.1029/2003GL019214.
Macrander, A., 2004: Variability and Processes of the Denmark Strait Overflow. Ph.D. thesis, CAU Kiel. http://e-diss.uni-kiel.de/diss_1283/
Macrander, A., U. Send, H. Valdimarsson, S. Jónsson, and R.H. Käse, 2005: Interannual changes in the overflow from the Nordic Seas into the Atlantic Ocean through Denmark Strait, Geophys. Res. Lett., Vol. 32, No. 6, L06606, doi:10.1029/2004GL021463
Macrander, A., U. Send, H. Valdimarsson, S. Jónsson, and R.H. Käse, 2007. Spatial and temporal structure of the Denmark Strait Overflow revealed by acoustic observations. Ocean Dynamics, DOI 10.1007/s10236-007-0101-x
Stern, M. E., 2004. Transport extremum through Denmark Strait, Geophys. Res. Lett., 31, L12303, doi:10.1029/2004GL020184.